MATCH: Markets, Actors and Technologies – A comparative study of smart grid solutions

Executive summary

Toke Haunstrup Christensen, Freja Friis & Hannah Mareike Marczinkowski

Tomas Moe Skjølsvold & William Throndsen

Michael Ornetzeder & Steffen Bettin

18 January 2019

ERA-Net Smart Energy Systems

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems, with support from the European Union's Horizon 2020 research and innovation programme.

INTERNAL REFERENCE

- **Deliverable No.:** -
- **Deliverable Name:** MATCH: Markets, Actors and Technologies: A comparative study of smart grid solutions. Executive summary.
- **Lead Partner:** Danish Building Research Institute, Aalborg University
- **Work Package No.:** -
- **Task No. & Name:** -
- **Document (File):** MATCH_Executive Summary
- **Issue (Save) Date:** 2019-01-18

DOCUMENT STATUS

	Date	Person(s)	Organisation
Author(s)	2019-01-17	Toke Haunstrup Christensen, Freja Friis, Hannah Mareike Marczinkowski, Tomas Moe Skjølsvold, William Throndsen, Michael Ornetzeder & Steffen Bettin	AAU, NTNU, ITA
Verification by	2019-01-17	Toke Haunstrup Christensen	AAU SBi
Approval by	2019-01-17	Toke Haunstrup Christensen	AAU SBi

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About ERA-Net Smart Energy Systems and MATCH

ERA-Net Smart Energy Systems (ERA-Net SES) – formerly ERA-Net Smart Grids Plus – is a transnational joint programming platform of 30 national and regional funding partners for initiating co-creation and promoting energy system innovation. The network of owners and managers of national and regional public funding programmes along the innovation chain provides a sustainable and service-oriented joint programming platform to finance projects in thematic areas such as smart power grids, regional and local energy systems, heating and cooling networks, digital energy and smart services, etc.

Co-creating with partners who help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

In addition, ERA-Net SES provides a knowledge community, involving key demonstration projects and experts from all over Europe, to facilitate learning between projects and programmes from local level up to European level.

www.eranet-smartenergysystems.eu

The *Markets, actors, technologies: a comparative study of smart grid solutions* (MATCH) project ran from February 2016 to October 2018 and was supported by ERA-Net SES.

https://www.match-project.eu

Improving energy efficiency and replacing fossil fuels with renewable energy are among the most important measures on the road to a sustainable energy system. This entails new ways of generating and consuming energy as well as new forms of relationships between energy producers and consumers. The MATCH project contributes to the shift towards a carbon-neutral energy system by focussing on the changing roles of small consumers in the future electricity system (the "smart grids").

The overall objective of MATCH was to expand our knowledge on how to design and implement comprehensive smart grid solutions that take into account the complexity of factors influencing the effectiveness and success of smart grid initiatives targeted at small consumers. The study is cross-disciplinary and based on detailed studies of current smart grid demonstration projects in Austria, Denmark and Norway. Through comparative analysis across cases and countries, the study identified key factors related to technology, market and actor involvement in developing integrated solutions that "work in practice". Furthermore, the project applied energy system analysis and scenarios to discuss the wider energy system implications by upscaling the studied cases and solutions.

On this basis, the project developed recommendations for decision-makers, engineers and project developers. This final part of the MATCH project is included in this report.

This is an Executive Summary of the MATCH project, which was funded by the ERA-Net Smart Energy Systems and lasted from February 2016 to October 2018 and involved partners from Norway, Austria and Denmark. Project website: https://www.match-project.eu/

1 Aim and approach

The overall objective of MATCH was to expand the understanding of how to design and implement comprehensive smart energy solutions that consider the complexity of factors influencing the effectiveness and success of smart energy initiatives targeted at small consumers.[1] Based on detailed case studies and comparative analysis, key factors related to technology, market and the involvement of social players or actor groups in developing integrated and workable smart energy solutions were identified. In addition, system implications of the studied solutions were analysed through energy system scenario analyses. The results from the project inform designers, system planners and policy-makers about how to develop better smart energy solutions for small consumers like households and SMEs (Small and Medium-sized Enterprises).

2 Methods

The analytical approach was interdisciplinary, covering expertise related to the following research fields: Consumer practices (practice theory), the interaction between users and technology (Science and Technology Studies), learning and experimentation in development of new technologies (Constructive Technology Assessment) and energy system analysis (using the EnergyPLAN model developed by Aalborg University).

The project applied a "mixed methods" approach to study the cases from different perspectives and ensure a qualified and elaborate analysis on how the specific smart grid solutions depend on different factors related to technology, market design and actor involvement. Thus, the project applied qualitative methods (e.g. interviews with small consumers and other relevant stakeholders), existing secondary data (e.g. evaluation studies or technical reports) and quantitative methods (in relation to energy system analysis). In total, about 80 semi-structured, qualitative interviews were performed, transcribed and analysed.

On basis of an overall analytical framework (developed in WP1; see Skjølsvold et al. 2016), detailed case studies were carried out in Austria, Denmark and Norway. In each country, three cases were selected for study (9 cases in total). The cases were existing pilot projects and they were selected strategically in order to cover three overall types of solutions often presented within the smart energy field:

- Demand-side Management (DSM) or Demand (Side) Response (DR), including both increasing energy efficiency and time-shifting consumption
- Micro-generation (i.e. distributed production of renewable energy)
- Energy storage solutions (i.e. thermal storage or chemical storage in batteries)

[1] The term "smart grid" was used in the original title of the project, however, it was decided to widen the scope to include smart energy solutions more broadly. For this reason, we will use the smart energy term in this summary.

On basis of these criteria, the following nine cases were selected (see Table 1):

Table 1. Overview of cases: Description, applied technologies, key actors and main target group

Country/ Case	Description	Applied Technologies	Key Actors	Main Target Group
Austria				
Köstendorf	Pilot and demonstration project with smart distribution grid field test	Local grid PV integration, combination of PV systems and batteries, PV systems and e-vehicles, testing smart grid Infrastructure	Regional DSO & ESCO, research institute, industrial group	Households, SMEs, public authorities
Rosa Zukunft	Pilot and demonstration project with Building-to-grid solution and DSM field test	PV systems without research focus, testing smart grid infrastructure, household level DR and energy feedback, heat-pumps, CHPs	Regional DSO & ESCO, research institute, housing association	Households
VLOTTE	E-mobility business implementation	Combination of PV systems and batteries, PV systems and e-vehicles, PV systems without research focus, testing smart grid infrastructure	Regional DSO & ESCO	SMEs & employees
Denmark				
Innovation Fur	Piloting and demonstration of balancing local energy exchange at the community micro grid level	Local grid PV integration, combination of PV systems with heat pumps or/and batteries, testing smart grid infrastructure	DSO & Municipality	Households
Project-Zero	Promote and facilitate energy efficient measures and local renewable energy to decarbonize consumption	PV systems without research focus, EVs and heat pumps as well as "smart" building energy renovations to achieve higher energy efficiency	DSO, regional Bank-Fund, Municipality	Households and SMEs
Samso Energy Academy	Community participation project to increase energy autonomy of the island	Testing potentials for reduce energy demand by regulate temperature and install energy efficient equipment (energy efficiency measures)	Dedicated Organization for project implementation	Households and SMEs
Norway				
PV demo Trondelag	Two related regional PV demonstration projects	Local grid PV integration, testing smart grid Infrastructure	Two regional DSOs	Households
Smart Energy Hvaler	Testing the potential for balancing the local grid	Local grid PV integration testing demand response and impact of smart technologies as PVs and e-vehicles	Regional DSO, Municipality, University	Households
ASKO midt-Norge	Large PV for decarbonisation of vehicle fleet and for on-site electricity use	PV systems without research focus, hydrogen production, hydrogen driven trucks	Large grocery wholesaler	SMEs & employees

For each case (pilot), detailed qualitative studies were carried out in order to document and analyse how complex sets of factors influence the effectiveness of smart energy initiatives in order to contribute to better and more comprehensive smart energy solutions. More specifically, the case studies analysed both the direct implications of smart energy solutions on the (everyday) practices of the users as well as how the solutions (and how they are used in practice) are integrated in a network of mutually dependent actors. A particular focus was on solutions that "work in practice". Here, we applied a broad definition of what it means to say that solutions "work". Overall, we defined the studied solutions as working successfully when relevant actor groups – through interaction between actors in local-situated networks – had been able to define, set up and test the studied solutions in real-life settings.

As part of the case studies carried out in WP2, prominent socio-technical configuration(s) were identified, mapped and described in detail. The results were reported in three country reports (Ornetzeder et al. (2017), Christensen et al. (2017) and Throndsen et al. (2017)). These reports included a mapping of the country-specific context relevant to the analysis of the specific cases (e.g. the energy system, existing smart grid landscape, market structure, etc.).

On basis of the case studies reported in the country reports, a comparative analysis of the cases was carried out in WP3 (reported in Ornetzeder et al., 2018a). The aim of this was to identify and discuss critical factors related to market, technology and actor-involvement that are decisive for designing integrated smart energy solutions for small consumers that work under real-life settings. More practically, this was done through identifying several "clusters of solutions" with one or more similar characteristics in common (e.g. similar phase of innovation, similar target group, similar function, or similar project aim). Each cluster consists of at least two working socio-technical configurations applied in at least two different cases. By developing such clusters of solutions, we provided a more stable basis for comparison and allowed for the discussion of aspects and patterns that help better understanding the success across projects and solutions.

Three clusters of solutions were identified and analysed in detail. In addition to this, a crosscutting evaluation of the role of users in the studied solutions were carried out. The four thematic fields of study are as follows:

- **Balancing generation and demand:** In this cluster, the focus was on solutions to better deal with variable renewable generation. The studied cases applied and tested several strategies for matching supply and demand, ranging from energy feedback & DSM (Rosa Zukunft) to smart charging (VLOTTE), the use of heat pumps and batteries at the household level (Innovation Fur) and the use for cooling or hydrogen production (ASKO).
- **Renewable powered company fleets:** In this cluster, the focus was on the development of solutions converting vehicle fleets to renewable energy sources through in-house developments aimed first at the companies' own needs. Two cases were analysed in direct comparison: VLOTTE project (a regional DSO developing a smart e-car park) and ASKO (large grocery wholesaler establishing a hydrogen infrastructure for hydrogen-powered commercial vehicles).
- **Comprehensive energy concepts:** This third cluster included cases aimed at providing complete solutions to achieve a maximum in terms of energy saving and use of renewables. The cluster focuses on households (100% renewable household in Köstendorf), apartment buildings (Rosa Zukunft), supermarkets (Samso, ProjectZero / ZERObutik), and sports facilities (Project Zero / ZEROsport) – in some examples as part of a regional energy transition plan (Samso and ProjectZero). Common for these cases is that a number of technologies, rules and practices work together in a custom-made manner to achieve ambitious energy targets.

- **User integration**: An additional topic for cross-country, cross-project and cross-solution comparison was user integration. As users are essential in all studied cases, a cross-case analysis offered an additional perspective on the success of the solutions.

In parallel with the comparative case studies of WP3, an energy system analysis was carried out (WP4) and reported in Marczinkowski & Østergaard (2018). This was informed by the findings from the case studies (WP2) and the main aim was to study the dynamic relations between different smart energy solutions for small consumers in order to provide recommendations on how to combine and integrate solutions on a system level. The outcome was a number of scenarios that visualize the system-related consequences of combining different solutions studied in MATCH and in the three different countries. In other words, this WP explored system-level implications of generalisations (upscaling) of the studied solutions.

Finally, MATCH concluded with WP5, which synthesised the findings from the previous work packages and developed concise recommendations for designers, planners and policy-makers. A comprehensive analysis on the role of price incentives for demand response in households was also developed in conjunction with this. Preliminary recommendations were presented to and discussed in detail with stakeholder audiences in each of the three partner countries. The results of these workshops were incorporated in the final recommendations (Ornetzeder et al., 2018b).

All in all, the findings of MATCH build on a combination of individual case studies, a comparative analysis carried out in close collaboration between all partners and a modelling of system effects.

3 Findings

The following summarizes the key findings from the analysis of the three clusters of solutions and the user integration:

- **Balancing generation and demand using solar PV and storage:** The success and viability of the studied solutions were highly dependent on a high degree of social interaction, learning, and exploitation of issues in local context. The projects that were most successful were the ones having made extensive and varied recruitment efforts consistent with aspects of social learning. Town hall meetings, involving different user groups, education and information campaigns were all useful for both recruitment and teaching people about the benefits of time shifting (and how to avoid expensive peak loads). Active participation and a positive judgment of the overall project could be seen in projects like Köstendorf, Innovation Fur and Smart Energy Hvaler, where users felt a sense of ownership with the project. They identified with the project aim or the larger vision of energy transition behind it.
- **Renewable powered company fleets:** The supportive political context and pre-existing resources and competence building in the region were crucial for the success of both solutions studied. For VLOTTE, this was the early success of the project as well as the network of research and university institutes. For ASKO, it was the intensive networks of innovation and manufacturing. In addition, the corporate culture functioned as an innovation driver. The ESCO of VLOTTE ventured into an unknown business field, and ASKO saw the promotion of an environmental solution as part of strengthening their own (market) position and to promote changes in the framework conditions for such socio-technical solutions. Furthermore, the “real-life” conditions of the demonstrations were important. For instance, the real-life conditions of VLOTTE helped to validate first ideas and to check employees’ acceptance and adoption of solutions. Related to this, the studied companies acted as user-innovators who benefitted from their own innovations.
- **Comprehensive energy concepts:** Common for the studied solutions is that they are part of comprehensive, ambitious, and community-led transition strategies that involve a wide range

of interconnecting initiatives, technologies and multiple actors. An essential factor for establishing and anchoring successful solutions was that they were community-driven. Thus, successful solutions are part of longer history of previous experiments, implementations and initiatives. Hence, the studied solutions represent single elements in a much wider spectrum of energy transition initiatives. Except for Rosa Zukunft, these solutions often build on pre-existing networks of actors, though one local key actor seems to be necessary for leadership on designing the solutions as well as driving and facilitating the processes and initiatives of cooperation, network building and communication.

- **User integration**: The most remarkable finding of this analysis was that, in most cases, a variety of different user types or roles contributed to the functioning of the solutions. Six different user roles and their respective characteristics were identified: Research partners, traditional or ordinary users, prosumers, energy citizens, affiliated users, and user-innovators. Since the different roles often occur in various combinations with each other, the resulting principle is a "bundle of user roles". These bundles were able to inform the technical functioning, to influence the way in which problems were solved, and to support the social and political stabilisation of the solutions. In summary, the diversity of perspectives, interests and requirements had a positive impact on the development and operation of the solutions.

In addition to the above analyses, we also made a comparative study of the role of economic incentives (price) for households to time shift consumption (demand response) as well as an analysis of energy system implications of the studied solutions (WP4). These separate studies resulted in the following findings:

- **The role of price in demand response for households:** The role of price-based incentives, like time-of-use pricing, for demand response in households was studied and reported in Christensen et al. (in prep.). Based on a comparative analysis of experiences from Smart Energy Hvaler (combining capacity-based tariffs and micro-generation), Rosa Zukunft (combining variable tariffs and visual feedback) and Innovation Fur (combining hourly net metering with micro-generation), the study showed that economic incentives under certain conditions do influence energy-consuming practices of households, but not in ways as anticipated by economic-rational conceptualisations widespread within economic, engineering and policy-making approaches. The effectiveness of price-based incentives is highly dependent on *other* elements of engagement, devices and competences that are – one way or the other – decisive for the actual impact of the pricing scheme. Also, the specific design of the time-of-use pricing scheme itself is important, as those designs that appear to work best are easy to understand for the users (households) and provides predictable variations in electricity prices. The study also showed that the material context plays a decisive role for demand response actions, as it is in general more difficult to time-shift consumption (especially to night hours) in multi-storey blocks than in detached houses (because of problems of bothering neighbours due to noise). Also, prosumption seems to have a positive influence on households' engagement in demand response.
- **Energy system implications of upscaling studied solutions:** The energy system implications of upscaling three studied smart energy solutions were explored by use of the energy system modelling tool EnergyPLAN. The three solutions were: 1) Combined Heat and Power and/or heat pumps replacing individual heating with PV support, 2) demand response and peak-shaving approaches and 3) dumb versus smart charging of electric vehicles (i.e. charging upon home arrival versus charging according to need and then it is smart from an energy system perspective). The scenarios in general show relatively little positive impact of the various solutions on a national level (measured by aggregated changes in CO_2 and fuel reductions by, e.g., smart electric vehicle charging). However, there are country-specific differences related to for instance different energy mixes that are important to consider. This is particularly visible

for the scenarios related to smart versus dumb electric vehicle charging. Here, the positive impact of smart charging is particularly evident in Denmark (adding an additional 1.6% CO_2 reductions compared to a scenario based on dumb charging), whereas the positive impact is rather limited in Norway and Austria. All in all, the Combined Heat and Power (and district heating) combination has a role to play particularly in the Austrian energy system, and it was found that heat pumps are well suited in the Norwegian context. In Denmark, electric vehicles must be well integrated using smart charging and possibly also V2G facilities to maximize positive impacts on the electricity system.

4 Conclusions and recommendations

- **Smart energy solutions work because they are designed as socio-technical configurations from the outset:** We have pointed out that successful implementation of the solutions depends on a well-designed interplay of social and technical elements. We argue that smart energy solutions should be considered as heterogeneous configurations from the very beginning.
- **Smart energy solutions work because they are supported by local anchoring activities:** We have shown that such solutions must rely on local anchoring activities and, based on our case studies, have made suggestions as to how this can be achieved in practice.
- **The effectiveness of tariff systems and price incentives depend on their social, legal and technical context:** We have discussed the role of tariff systems and price incentives (Time-of-Use pricing) and have concluded that financial incentives often work as a "marker" or "signifier" that may attract consumers' attention. However, the actual effectiveness of pricing schemes is determined by the practical context of the schemes, i.e. the overall socio-technical configuration the pricing scheme is embedded in.
- **The development of workable solutions depends on social learning processes:** We have addressed the issue of balancing consumption and demand, and pointed out that the success of such approaches essentially depends on the extent to which users are provided knowledge, tools, and techniques with which they can successfully adapt to variable prices and enter processes of learning.
- **Technology users play a multifaceted, decisive role:** We have studied the role of users in innovation processes and seen that successful solutions are simultaneously influenced by a variety of user roles already during early phases of development. Based on this knowledge, we recommend that it is important to ensure a multiplicity of user roles (and their associated perspectives, interests and requirements) being included in the design and realization of solutions.
- **Solutions that work well locally does not necessarily have a significant (positive) impact from the point of view of the entire system:** On the basis of our energy system modelling, we have suggested that it is important to examine the various systemic effects of locally successful solutions for existing energy systems (regional, national) before replicating or upscaling them (see also the following).

One topic repeatedly addressed over the course of the project and discussed in more detail in the three public MATCH workshops carried out in 2018 relates to **the upscaling and increased dissemination of already available and well-working smart energy solutions**. Given the ambitious energy policy goals within the European Union, this is a legitimate issue. A few observations can be made in relation to this on basis of the MATCH findings:

- Although we have presented configurations that are successful, there is hardly any one solution in our sample that could be distributed on a large scale in its present form. There are three main reasons for this: First, the success of these solutions depends on a coordinated interplay of elements and well-functioning local anchoring activities. This means, on the other hand, that replication depends on appropriate adaptation services: in another local or regional context, different elements of a successful configuration would need to be arranged differently. Second, from the point of view of the system as a whole, the widespread dissemination of a solution often does not appear to make sense, but rather the combination of many different solutions. Third, an explicit recommendation for the accelerated dissemination of solutions would have to include an external assessment of the direct effects and possible unintended consequences on the system level, something that could not be achieved in the present project.

- However, we were also able to observe diffusion processes in the context of this research. Some operate mainly via traditional *market mechanisms*, others essentially via locally established *social networks*. An example of the first type of distribution is the building-to-grid solution in the city of Salzburg. Following the example of the Rosa Zukunft project, the local energy supplier has already implemented similar projects in cooperation with local housing developers. Another example is the electric vehicle fleet solution from the VLOTTE project: the experience gained over the years is already being offered as part of a consulting service. ProjectZero in the Danish municipality of Sønderborg represents an example in which solutions are predominantly disseminated via social networks. ProjectZero is a public-private partnership between several local (energy-related) companies and the municipality of Sønderborg. The project acts as an intermediary that promotes and coordinates all relevant actions that support the local energy transition. The dissemination of solutions is very effective with this model, but remains limited to the respective region.

Another way in which the results of local demonstration projects can be disseminated is by *generalising* specifically selected experiences. We found such an example e.g. in the case of the low-voltage grid field test in the municipality of Köstendorf in the province of Salzburg. The conducted real-world experiments showed that – at least up to a certain extent of PV distribution – the existing grid is sufficiently protected against overloading by phase shifting (phase-shifted current is fed into the low-voltage grid). Consequently, high investment costs for controllable transformers can be avoided with this measure in the future. The grid operator translated this result into an obligatory requirement for all new PV systems in the area.

5 Project reports (deliverables)

Christensen, Toke Haunstrup; Friis, Freja (2017): *Case study report Denmark - Findings from case studies of ProjectZero, Renewable Energy Island Samsø and Innovation Fur*. Danish Building Research Institute, Aalborg University. Deliverable D2.2.

Marczinkowski, Hannah Mareike; Østergaard, Poul Alberg (2018): *Energy system analysis*. Department of Planning, Aalborg University. Deliverable D4.1.

Ornetzeder, Michael; Sinozic, Tanja; Gutting, Alicia; Bettin, Steffen (2017): *Case study report Austria - Findings from case studies of Model Village Köstendorf, HiT Housing Project and VLOTTE*. Institute of Technology Assessment, Austrian Academy of Sciences. Deliverable D2.1.

Ornetzeder, Michael; Bettin, Steffen; Gutting, Alicia; Christensen, Toke Haunstrup; Friis, Freja; Skjølsvold, Tomas Moe; Ryghaug, Marianne; Throndsen, William (2018a): *Determining factors for integrated smart energy solutions*. Institute of Technology Assessment, Austrian Academy of Sciences. Deliverable D3.1.

Ornetzeder, Michael; Bettin, Steffen; Christensen, Toke Haunstrup; Friis, Freja; Marczinkowski, Hannah Mareike; Skjølsvold, Tomas Moe; Ryghaug, Marianne; Throndsen, William (2018b): *Recommendations for researchers, designers and system planners*. Institute of Technology Assessment, Austrian Academy of Sciences. Deliverable D5.1.

Skjølsvold, Tomas Moe; Ryghaug, Marianne; Throndsen, William; Christensen, Toke Haunstrup; Friis, Freja; Ornetzeder, Michael; Sinozic, Tanja; Strauß, Stefan (2016): *Studying smart energy solutions for small to medium consumers*. Norwegian University of Science and Technology. Deliverable D1.

Throndsen, William; Skjølsvold, Tomas Moe; Koksvik, Gitte; Ryghaug, Marianne (2017): *Case study report Norway - Findings from case studies of PV Pilot Trøndelag, Smart Energi Hvaler and Asko Midt-Norge*. Dpt. of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology. Deliverable D2.3.